CHARACTERIZATION OF THE FLOW FIELD, WIND SPEED PROFILES AND TURBULENCE INTENSITY IN ENVIRONMENTAL WIND TUNNELS FOR MEASUREMENT OF AGENT FATE

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ABSTRACT

Surface evaporation and desorption sub-models in VLSTRACK require measurements of chemical warfare agent evaporation and desorption under environmental conditions. A 5cm square by approximately 1 meter wind tunnel for chemical agent measurements was developed with optional strakes and roughening elements to add turbulence. Flow was developed in the pull-mode by an electric blower system. Several candidate intake geometries were designed that allowed controlled restriction of air intake to control wind speed. The flow field was characterized as a function of several intake control geometries and as a function of the presence or absence of the turbulence elements. A micrometer positioning device was employed to traverse the wind tunnel cross section with a subminiature hot wire anemometer. A TSI Model IFA-300, temperature-compensated, hot wire anemometry system was utilized for all measurements. The experimental and computational fluid dynamic flow field results were documented. The upper and lower limits of wind speed available from the electric blower and intake restriction systems were determined. The symmetry of the flow field with and without turbulence elements was also determined. The chemical droplets are placed on substrates on the floor of the wind tunnel; therefore, flow field measurements close to the floor were emphasized. Finally, the reproducibility of the wind speed was measured as a function of blower power settings and intake restrictions levels.

INTRODUCTION

The development of accurate hazardous prediction computer models such as VLSTRACK and HPAC, depend greatly on having a solid understanding of how the various hazardous chemicals of interest evaporate under a wide variety of ambient conditions: temperature, humidity and wind speed. This type of information can be obtained in several ways, small scale laboratory experiments, larger scale wind tunnel experiments or open air field tests. This paper is concerned with the development of a small scale laboratory wind tunnel, which was designed to fit inside a typical chemical hood while still providing realistic wind speeds, and having the ability to accept several different substrate materials test surfaces. Several means of controlling the test section wind speed and turbulence level were investigated. An adjustable 2.5-cm piston located in the floor of the test section permits various thickness test substrates to be positioned even with the test section's floor. Stainless steel and Lexan (poly carbonate) versions of the wind tunnel were fabricated to cover special testing needs. Hotwire anemometry was used to measure the centerline wind speed, and velocity profiles above the test section piston, for both wind tunnel versions.

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TUNNEL DESIGN

The general layout of this wind tunnel was selected to approximate that of larger environmental type wind tunnels. Typically environmental wind tunnels are closed circuit, but in order to conserve the limited space within the chemical hood and to eliminate the need to filter the return air, an open circuit design was chosen early in the design process. The tunnel cross-section of 5x5cm was chosen to maximize space in the chemical hood and to achieve the desired upper limit test velocity of 9m/s. This cross-section allowed a large enough test section for chemical fate tests using small substrate specimens, while also allowing for a smaller blower to cover the test velocity range. Although the tunnel could be sealed to prevent leaks, the additional precaution of placing the blower downstream of the test section guaranteed that the test section would be under negative pressure, thus reducing the danger of the hazardous chemical vapor escaping. This arrangement had the drawback that the motor/blower drive section would most likely become contaminated during testing and thus would have to be decontaminated or since the blowers are relatively inexpensive they could be replaced. The motor/blower selected for this design was a miniature brushless DC centrifugal blower from Brailsford & Company, Inc. This blower operates within a voltage range of 18-30v, which offers a limited means of flow control through the wind tunnel.

Initially a prototype tunnel was constructed from Plexiglas to check out various design features. Several difference tunnel lengths were tested to determine the optimum length required for fully developed flow in the test section. An overall tunnel length, not including the blower or optional inlet section, was chosen to be 76cm. This included an entrance section with screen and straw flow straighteners followed by a constant area section 30cm long for flow development. The next section permits the tunnel to be configured with and without turbulence generating devices. In the clean configuration (no turbulence generating devices installed) an additional 20cm of fetch is provide upstream of the test section. In the turbulence generation configuration, see Figure 1, the 20cm section begins with a set of turbulence strakes, which represent a series of thin, evenly spaced spikes with a height of approximately half the wind tunnel. Just downstream of the strakes and extending an additional 15cm is a series of small cubes (roughness elements). The last 5cm of the turbulence section is clean and leads into the test section. The test section is 10cm in length with a 2.5cm adjustable piston in the floor of the tunnel with an assess port directly above the piston in the ceiling. In the stainless version, glass windows make up the sidewalls of the test section. Downstream of the test section and just upstream of the blower is a 16cm diffuser section. Figures 2 and 3 show the stainless steel and Lexan wind tunnels respectively.

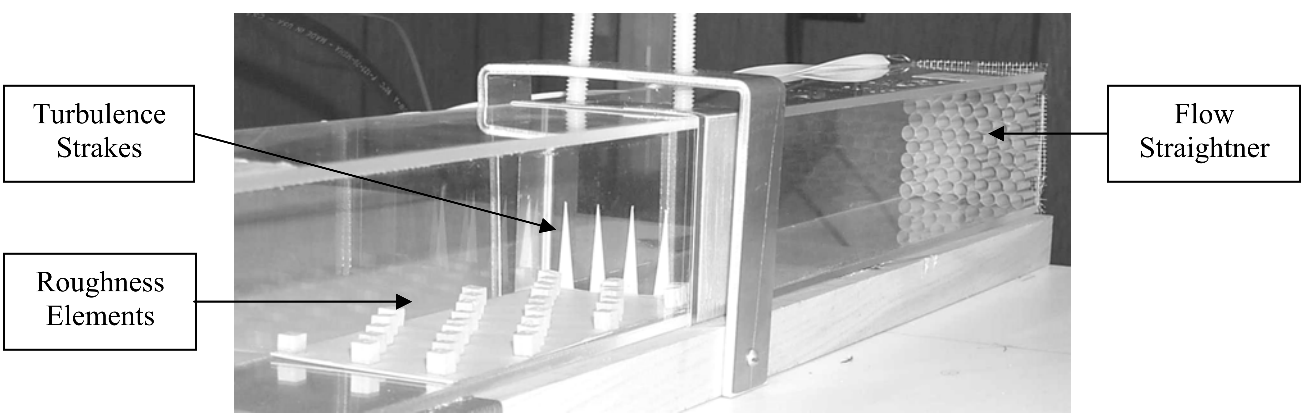

Figure 1 Soda straw flow straightner , turbulence strakes and roughness elements

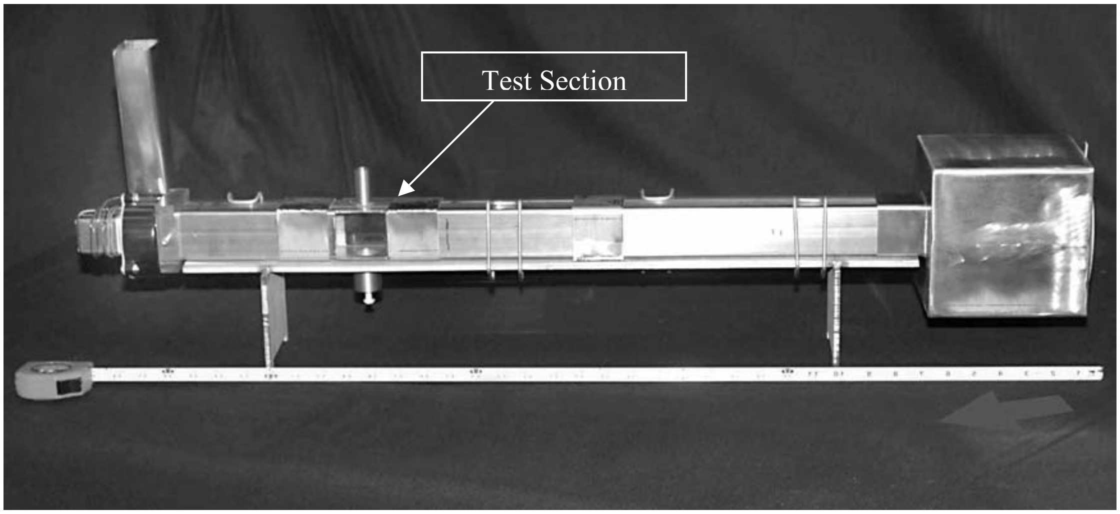

Figure 2 Stainless Steel Chemical Hood Wind Tunnel

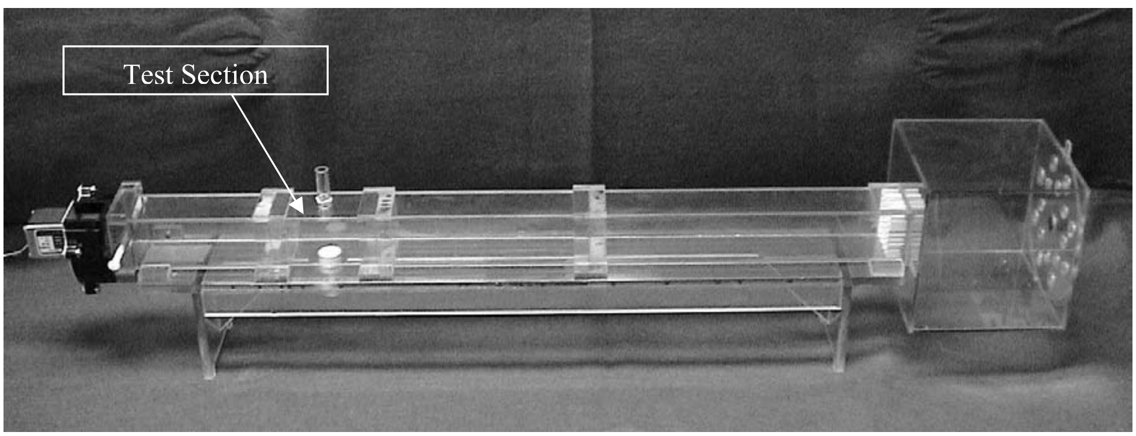

Figure 3 Lexan wind tunnel in clean configuration.

Due to the limited range of flow control of the motor/blower, especially at the minimum velocity range three different inlet configurations were considered. The three inlets were identified as the iris, multi-hole and multi-slot and are presented in Figure 4. The entire set of variable opening inlets was designed such that at the 100% setting, the open area is equal to the area of the cross-section of the wind tunnel. A variable area inlet provided the ability to constrict the flow to the wind tunnel and thus allow lower test section velocities to be achieved. The best performing variable inlet was the multi-hole inlet, and thus was selected for use with the wind tunnel. Although not the optimum approach, placing the adjustment at the entrance to the tunnel eliminated the need to decontaminate the flow adjustment mechanism. A drawback to this method of flow control was that by varying the inlet area, the static pressure was also varied. This would not permit an overall mean velocity calibration to be determined for the test section. Future modifications to the wind tunnel will consider placing the flow control downstream of the test section near the blower, which should allow a means of correlating the tunnel centerline velocity to the test section static pressure.

EXPERIMENTAL MEASUREMENTS

Numerous experimental measurements were made on the prototype, stainless steel and Lexan wind tunnels to quantify and characterize the flow fields through each configuration. For the majority of the measurements, a constant temperature hot-film anemometer (TSI IFA-300 system) was used to record velocity and turbulence intensity. Centerline velocity measurements were made as a function of blower voltage and inlet area opening. Velocity profiles and turbulence intensity measurements were made above the test section's adjustable piston for selected inlet area openings and blower voltage settings. Because the motor/blowers were a relatively inexpensive, off-the-shelf item that was considered disposable, the repeatability of several blowers with respect to voltage was tested.

Figure 4 Inlet configurations: multi-slot (left), iris (center) and multi-hole (right).

MOTOR/BLOWER FLOW CHECK

Four different motor/blowers were checked for their flow rate vs. DC voltage setting. Of the four motor/blowers checked, all but one indicated good flow rate repeatability for a given voltage setting. The one unit with slightly reduced performance was an older blower that had been used on the prototype wind tunnel and had a build up of talcum powder on the fan. This indicates the need to assure that the blower is kept clean or flow performance can suffer. The flow results are shown in Figure 5. It should be noted that measured flow rates were lower than those obtained in the wind tunnel because of the higher pressure drop across the flow meter used to make these measurements.

STAINLESS STEEL WIND TUNNEL

The main purpose of the stainless steel wind tunnel is for evaporative studies of hazardous chemicals. Centerline velocity measurements were made in the stainless steel wind tunnel with the turbulence generating devices installed and not installed (clean configuration), at motor/blower voltage settings of 18 to 30v in 2v increments, and at the following inlet area openings: 100% 89%, 77%, 66%, 54%, 44%, 33%, 24%, 16% and 8%. 100% refers to the multi-hole inlet being full open. The centerline velocity data is shown in Figure 6 and 7 for the turbulence-generating device installed and the clean configuration, respectively. Nine velocity profiles as a function of height above the test section's adjustable floor piston (0.25mm to 46mm) were taken for the following flow conditions: 18, 24 and 30v, openings of 100%, 33% and 8%, and with and without turbulence-generating devices. These results are shown in Figures 8 and 9.

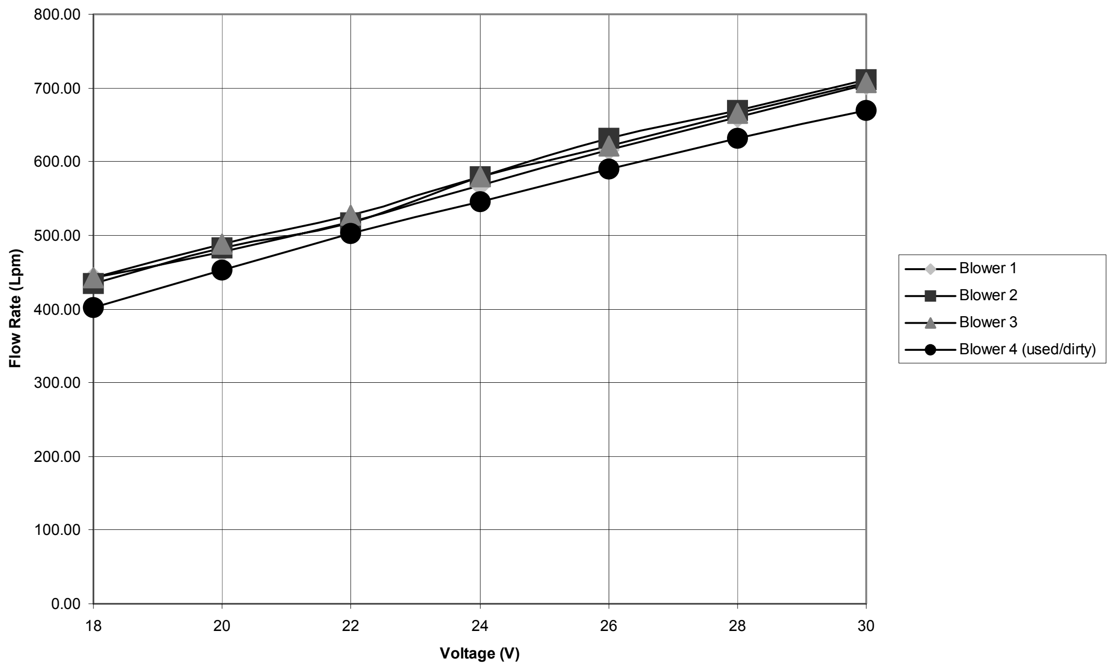

Figure 5 Brailsford motor/blower flow rate comparison.

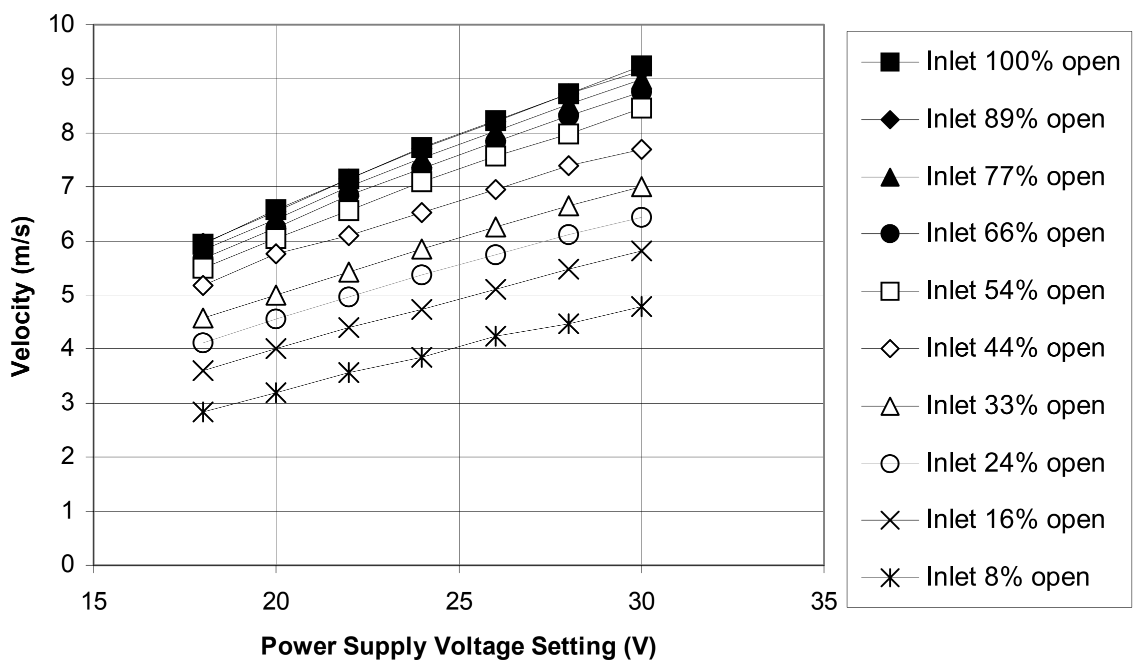

Figure 6 Stainless steel wind tunnel centerline velocity measurements with turbulence generating devices.

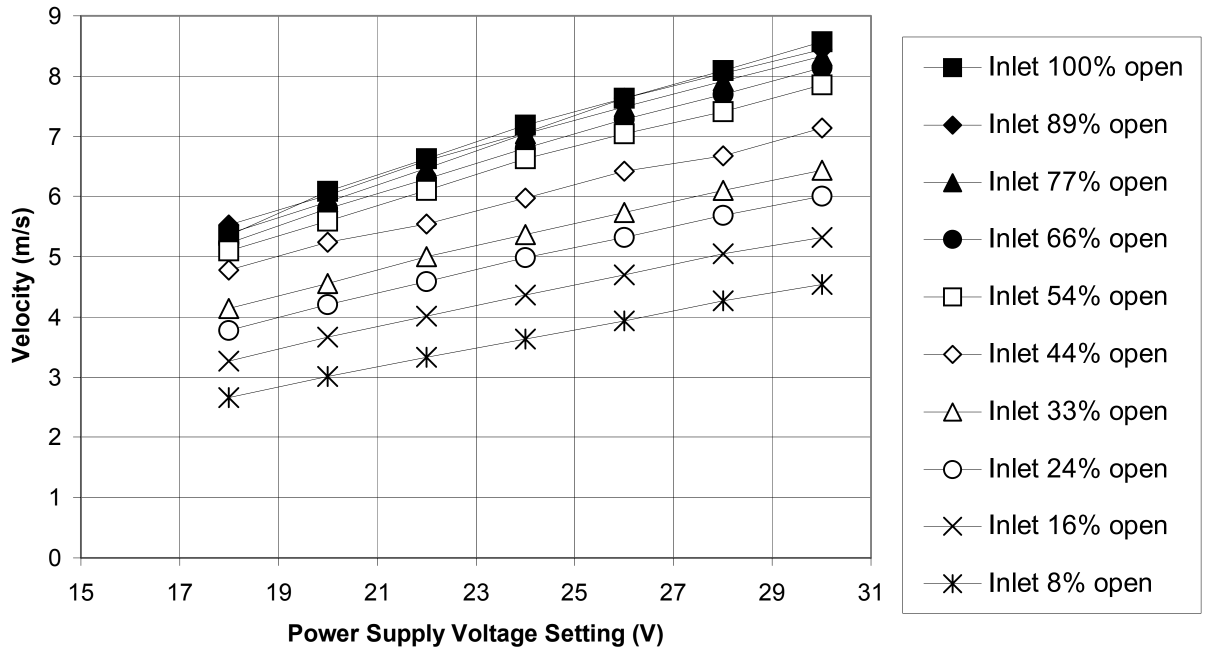

Figure 7 Stainless steel wind tunnel centerline velocity measurements without turbulence generating devices (clean configuration).

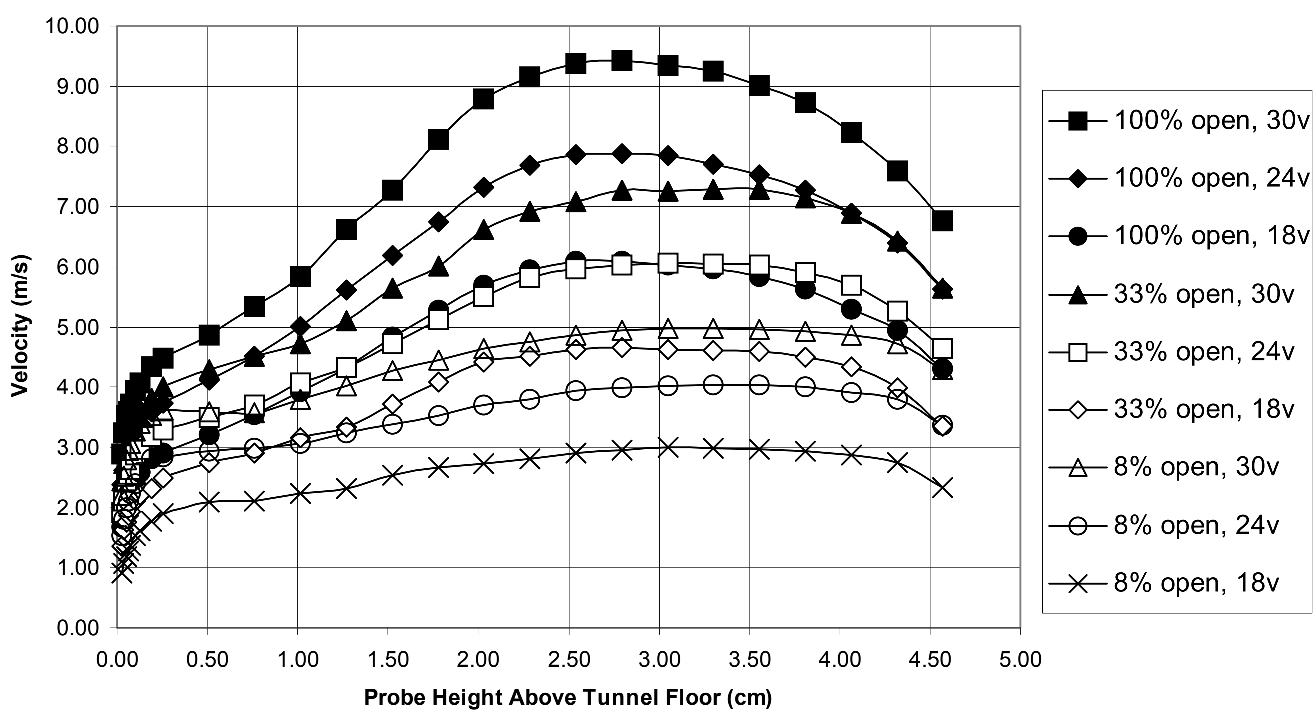

Figure 8 Stainless steel wind tunnel test section velocity profiles with turbulence generating devices.

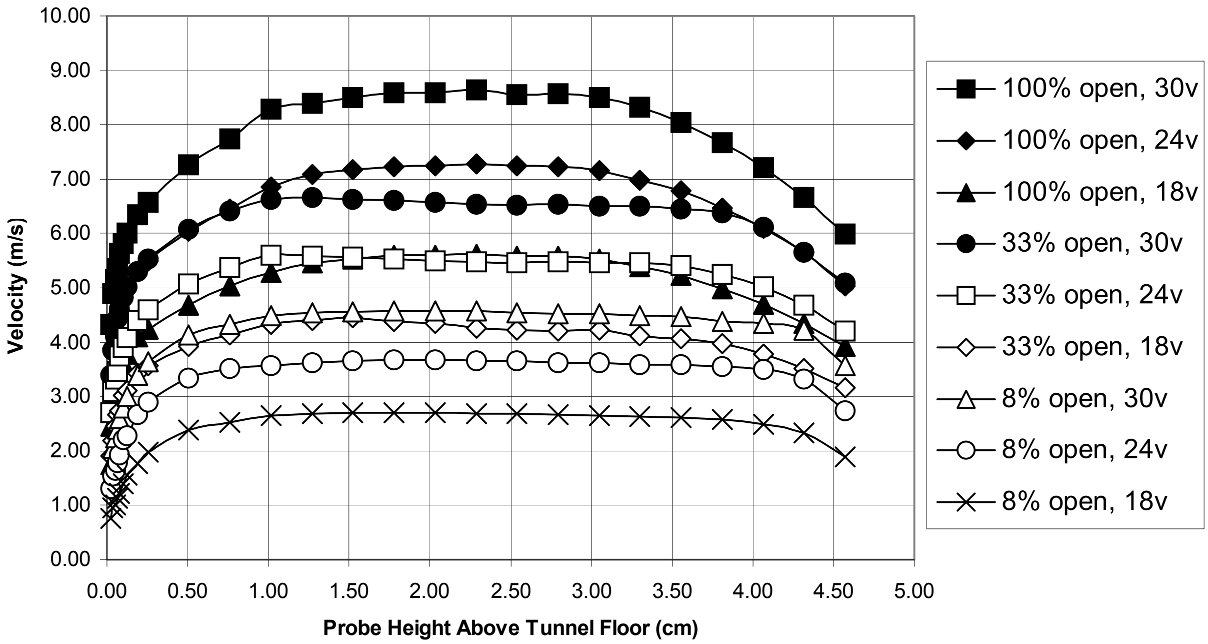

Figure 9 Stainless steel wind tunnel test section velocity profiles without turbulence generating devices (clean configuration).

LEXAN WIND TUNNEL

As with the stainless steel version of the chemical hood wind tunnel, a similar set of calibrations was made that included the centerline velocity, test section velocity profiles and turbulence intensity profiles on the Lexan wind tunnel. For brevity, the Lexan wind tunnel results will not be presented at this time. To summarize, the Lexan wind tunnel results were similar to the stainless tunnel results and followed the same general trends. However, the Lexan results typically were between 1 to 0.5 m/s lower than the stainless steel results. Part of the reason for the difference in magnitude is due to the 15cm exhaust tube used on the blower/motor of the stainless steel wind tunnel's motor/blower. An exhaust tube was not available when the Lexan tunnel was characterized. The exhaust tube helps to control the blower exhaust, thus increasing the efficiency of the blower and correspondingly increasing the tunnel velocity about 0.5 m/s.

DISCUSSION OF RESULTS

Overall both the stainless steel and Lexan wind tunnels operate satisfactorily and should provide a good test environment for hazardous chemical compound evaporative studies. The tunnels with their off-the-shelf motor/blowers provide a good range of wind speeds, especially in the mid to upper speeds of interest. At the lower wind speed limits, the blower can be replaced with an endcap equipped with a 3mm sampling port and the typical sampling flow rate of the gas chromatograph used for analysis can be used. In addition the multi-hole inlet can be replaced with a transition section that allows the tunnel to be directly connected to an environmental conditioning unit which conditions the wind tunnel supplied air to the appropriate temperature and humidity.

The velocity profiles measured above the adjustable test section piston were made with the assumption that the chemical droplet was either a very thin film covering the substrate or that the droplet had been completely absorbed into the substrate. Taking into account the effects of a sessile droplet on the surrounding flow field is beyond the scope of the investigation, but is being considered for future study.

The use of the turbulence-generating devices helped to increase the turbulence level of the flow away from the floor of the wind tunnel. However, it is not presently known if the resulting boundary-layer profile is suitable for this type of testing. The resulting measured profiles appear to approximate the classic boundary-layer under the influence of an adverse pressure gradient, typically associated with flow separation, or the non-neutrally buoyant flow field being effected by a temperature gradient. Further study of the effects of the turbulent generating devices is warranted. In the mean time, the resulting clean configuration velocity profiles more closely approximate the Frost curves used in atmospheric surface layer modeling. It is recommended that for the immediate future that the clean configuration wind tunnels be used for the evaporative studies.

CONCLUSIONS

A small scale, chemical hood, wind tunnel for hazardous chemical evaporative studies has been designed and fabricated in two version, stainless steel and Lexan. Several different adjustable inlets were evaluated, with the multi-hole adjustable inlet providing the best performance.

The tunnels are powered by inexpensive miniature DC motor/blowers, which have been shown through volumetric flow studies to provide fairly repeatable results between different blowers. Also it was noted that accumulated dirt on the blower’s fan could adversely affect blower performance.

Centerline velocity measurements were made in both the stainless steel and Lexan wind tunnels as a function of the motor/blower voltage and the percentage of inlet opening. Boundary-layer profiles were measured for selected motor/blower voltage settings and inlet openings for both clean and turbulence generating devices.

Until a better understanding into the resulting boundary-layer profile due to the turbulence generating devices can be achieved, the current recommendation is to use the clean (no turbulence generating devices) configuration of the wind tunnels.

The current chemical hood wind tunnel appears to be a good first design to support hazardous chemical evaporative studies. Modifications to improve the design are currently underway and include a transition/turning vane section to connect the wind tunnel’s inlet directly to the environmental conditioning unit and an investigation into moving the adjustable opening inlet from the tunnel’s entrance to just up stream of the motor/blower.

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